DESIGN AND TESTS OF SOLID AEROPLANE WIRE CONNECTIONS

BY

H. W. HAHN

J. E. SULLIVAN

ARMOUR INSTITUTE OF TECHNOLOGY

1916

THE DESIGN AND TESTS OF SOLID AEROPLANE WIRE CONNECTIONS

A THESIS

PRESENTED BY

Herbert W Hahn

Joseph E Sullivan

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN CIVIL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

CIVIL ENGINEERING

APPROVED:

Alfred E. Phillips
PROFESSOR OF CIVIL ENGINEERING

Raymond
DEAN OF ENGINEERING STUDIES

DATE May, 22, 1916

DEAN OF CULTURAL STUDIES

PREFACE

The authors aim has been to design and test a solid aeroplane guy wire connection. No claim to originality to the subject matter is made. The arrangement and treatment is however new.

The authors are under great obligation to many persons who have aided in various ways, especially to Professor Wells of the Civil Department of the Institute, who has aided greatly in the progress of the work. They are greatly indebted to Mr Huntly of the Mechanical Department for his aid in the testing laboratory.

Herbert W Hahn

Joseph E Sullivan

May 20, 1916.

TABLE OF CONTENTS

Introduction	1
Procedure	5
Data	10
Summary	23
Sketches and Pictures	

INTRODUCTION

The unfavorable results of tests of solid aeroplane wire connections have again presented the problem for consideration. Investigation of the causes of failure seem to indicate that in most cases there has been a violation of respect for the requirements governing the use of the wire.

To realize what these requirements are, it may be well to first enumerate the properties and characteristics which are responsible for the difficulties.

The wire commonly used is a music wire, sometimes called aeroplane wire. It is extremely hard and brittle. The ultimate strength is about 240, 000 lbs. per sq. in., as verified by tests on the Olson testing machine which was used throughout the series of tests.

Roebling recommends that the curve over

which bending takes place, be not less in diameter than ten times that of the wire so as to reduce the internal stress as far as possible.

To eliminate this, the decision was to use the wire straight, but even this led to more trouble. No reliance could be attached to an ordinary clamp arrangement that depends on tightening up a bolt and nut because of the varying degree to which the tightening would take place. Aside from endeavors toward economy of expense, weight, employment of non-skilled labor, poor quarters under which repairs were to be made, and the limited access to tools were continually kept in mind.

As mentioned before, the use of a straight wire, in order to eliminate the difficulties encountered in bending, was to be attempted. The bond between solder and

wire was to be included in the first investigation, because previous tests made by Zack, Smith and Hollowed in 1910, of a stranded wire resulted in the wire pulling out of the solder. It was thought the unit bond stress between the wire and the solder had been exceeded.

Investigations showed that it required about one square inch of bond area per 1600 lbs. of tension on the wire and this value was used to give an approximate area required for each size of wire. For instance the ultimate strength of an 1/8 inch diameter wire is about 3000 lbs.;then 3000/1600 would be about two inches of bond area required. The circumference of the wire is about 3/8 of an inch. 2 divided by 3/8 would be about 5 1/3 inches that the wire should be inserted to just pull out of the solder when a tension equal to the ultimate strength of the wire was applied to

the connection.

It was thought advisable to use at least four sizes of wire in order that the connection designed would be suitable to all diameters of wire. Care was taken to choose wire that had a diameter that bore a factoral relation in order that some definite relation might be determined between the diameter of wire and tube and the length of the insertion. Numbers 40, 36, 22, and 17 which have diameters about 1/8, 1/10, 1/16 and 1/20 of an inch respectively, were chosen.

PROCEDURE

Music wire is made of high carbon steel, and on this account it was thought that heating the wire would draw the temper, and thus reduce the strength of the wire. On account of the small space in which to work the soldering was not attempted in the usual way, i.e. by the use of a soldering iron. By this means, it would be impossible to get the solder down into the tube because it would cool as soon as it touched the cold wire or the inside of the tube. A few trials in this way proved that this method could not be made use of.

The next procedure adopted was the following. The tube was flattened at one end as shown in Fig. 1 by crushing the walls in a vise. As the tubing is coated with a grease

to prevent rusting, it was first necessary to remove this in order that the solder might form a good bond. The tube was cleaned thoroughly with gasoline, much the same way that the barrel of a rifle is cleaned, i.e. by means of a brush ram rod. After treatment in this way the inside appeared very bright. The tube was then filled with soldering acid, which is a composition of hydrochloric acid and zinc. The reaction is as follows;

$$2\ Hgcl + Zn = Zncl_2 + 2H$$

The tube placed on end in a container allowed the acid to leak out very slowly through the closed end. The tube was then ready for the solder. Care should be taken to see that all the acid is out of the tube before starting to introduce the solder. Should the solder be allowed to enter while there still is acid in the tube it would cause the solder to spatter out when heat was applied. The tube was then

gripped in the vise at the flattened face, and heated with a torch. Care was taken to heat the tube uniformly in order to prevent heating to a red glow. Wire solder was used which is half tin and half lead, made in the shape of wire. This form of solder permits easy entrance to the tube as it fits in without any waste. The wire solder was inserted into the tube, melting as it touched the inside walls. Heat was applied at the same time. When the solder had filled the tube the heat was removed and the wire inserted into the melted solder. As the wire was inserted the solder flowed out of the tube and was caught by a special designed apparatus for this purpose. The wire should be allowed to enter the solder gently and not simply dropped, as this will cause an unnecessary boiling over of the solder. Several connections were made in this way, one of which was cut in

section as shown in Fig.2. The results together with the section showed that the solder did not cause bond between the tube and the wire at every point. To remedy this difficulty it was suggested to quickly cool the connection in some way after the wire had been inserted, so as to shrink the solder at every point. This method was adopted by applying a rag, saturated with water, to the connection. When this was tried the solder which apparently filled the tube shrank to some distance inside. The connection was again heated and the wire moved about in the solder to help fill every point. More solder was then added and the shrinking process again applied. The solder at the open end of the tube could be seen gripping the wire as it was shrunk. Several connections were made in this way but on testing, the solder and wire pulled out. The bond between the solder and wire was satisfactory but there

did not see to be good bond between the solder and the wall of the tube. It was then thought advisable to dent in the side of the tube by means of a wedge hammer. This idea was carried out and on testing it was found that the desired bond between solder and wall had been obtained.

It should be clearly understood that the bond area i.e. the length to which the wire is inserted in the tube is a very important factor in the design. The length of each insertion is given with the data sheets and a discussion of the factor is taken up later.

NUMBER 40

Tests.		Ult. strength.
I		2980
2		2930
3		3020
4		2980
5		2970
6		2980
7		2975
8		2940
9		2960
I0		2950
II		2970
I2		2990
I3		2965
I4		2980
I5		2970
	Average	2970

NUMBER 40

No. of tests IO 3" Insertion.

Tests	Ult. strength.
I	I400
2	I480
3	I380
4	II80
5	I650
6	I490
7	I360
8	I290
9	I410
IO	I460
Average	1480

In the above tests the wire held to the solder but the solder pulled out. Therefore it is necessary to prefect the bond between the solder and the tube.

NUMBER 40

No. of tests 4" Insertion.

Tests	Ult. strength.
I	2500
2	2500
3	2680
4	2640
5	2590
6	2600
7	2540
8	2680
9	2670
IO	2500
Average	2550

In the above tests the tube was dented to form a mechanical bond, the lack of which caused failure in the previous tests. All the connections failed where the tube had been flattened. Tubing with greater cross sectional area must be used.

NUMBER 40

No. of tests 10 $5\frac{1}{2}$" Insertion

Tests	Ult Strength
1	3000
2	3010
3	3005
4	3000
5	3010
6	2995
7	3000
8	3005
9	3010
10	3005
Average	3004

In all the above tests the wire broke. This connection therefore is satisfactory.

NUMBER 36

Tests	Ult. Strength
1	1950
2	1960
3	1950
4	1945
5	1950
6	1950
7	1950
8	1950
9	1950
10	1955
11	1960
12	1950
13	1950
14	1955
15	1950
Average	1952

NUMBER- 36

No. of tests IO — 3" Insertion

Tests	Ult. Strength
I	I800
2	I755
3	I765
4	I645
5	I805
6	I807
7	I800
8	I700
9	I770
IO	I800
Average	1770

In all the above tests and also in all that follow the tube was dented.in Failure occured here between the wire and solder. Therefore the bond area had to be increased by inserting the wire farther into the tube.

NUMBER - 36

No. of Tests IO 4" Insertion

Tests.	Ult. Strength
I	I945
2	I985
3	I980
4	I960
5	I940
6	I950
7	I940
8	I970
9	I945
IO	I955
Average	1955

In all the above tests the wire broke. This connection is therefore suitable neglecting a factor of safety.

NUMBER 22

Test	Ult. strength of wire
I	565
2	575
3	580
4	590
5	580
6	570
7	570
8	575
9	565
I0	575
II	580
I2	585
I3	560
I4	570
I5	585
Average	575

NUMBER 22

No. of tests IO 2" Insertion

Tests	Ult. strength
I	550
2	400
4	535
5	500
6	550
7	450
8	480
9	430
IO	480
Average	437

Failure occured here between the wire and the solder. Therefore the wire had to be inserted farther into the tube.

NUMBER 22

No. of Tests IO — $2\frac{1}{2}$" Insertion.

Tests	Ult. Strength
I	640
2	624
3	640
4	635
5	650
6	630
7	640
8	645
9	630
IO	650
Average	638

In all the above tests the wire broke. The connection is therefore suitable neglecting a factor of safety.

NUMBER I7

Test	Ult. strength of wire.
I	380#
2	380
3	384
4	365
5	379
6	382
7	378
8	384
9	38I
I0	380
II	385
I2	380
I3	370
I4	379
I5	385
	Average 385

NUMBER I7

No. of Tests IO I" Insertion

Tests	Ult.Strength
I	I80
2	I80
3	I60
4	I40
5	I80
6	I70
7	I85
8	200
9	I90
IO	I85
Average	176

In all the above tests the wire pulled out. This connection therefore is not satisfactory. Here again the results show that it is necessary to increase the bond area.

NUMBER I7

No. of Tests IO 2" Insertion

Tests		Ult.Strength.
I		4I0
2		409
3		400
4		405
5		390
6		400
7		380
8		4I0
9		400
IO		405
	Average	410

In all the above tests the wire broke. This connection is therefore suitable neglecting factor of safety.

SUMMARY

The data recorded gives a clear idea of what is to be expected of the connection and the method and necessary factors of its construction. To repeat, let it be remembered that the most important of all the factors in this design is the necessary bond area between the wire and the tube. This means the length that must be inserted into the tube in order to give sufficient area for the bond. A preliminary discussion of this was taken up in the first pages of this work but an exact consideration will now be considered.

In order to determine the length of insertion the following scheme was adopted. From the data recorded the average ultimate strength of the connection and the length of insertion were known. The area of insertion can

therefore easily be computed. By dividing the average ultimate strength of the connection by the total bond area of wire the tension per square inch of wire insertion can easily be computed. Using this as a basis of calculation it would be easy in any case, knowing the ultimate strength of the wire, to determine the length of insertion. It will be noticed however that the tension per square inch of bond increases as the ultimate strength of the wire decreases. Calculating with the smallest tension per square inch of bond and using a factor of safety the connection should be designed with great safety. The figures here given show the ultimate strength of the wire, the average tension per square inch of bond area, the insertion and approximate diameters.

Ultimate Strength	Ten./ sq. in. of bond	Diam.	Inser.
2970	1215	1/8	5
1952	1540	1/10	4
575	1870	1/16	$2\frac{1}{2}$
385	1950	1/20	2

From the above it can be seen that for twice the diameter of wire the length of insertion should be twice as much. This gives a clear and easy rule for the insertion as verified by results.

The second point of great importance in the construction is the following. The tube must be dented in to give a mechanical bond between the solder and the inside of the tube. Without this the connection is useless. The dents should be staggered and placed about three quarters of an inch apart. There should be about four rows of these

around the tube.

Additional precaution could be taken by extending the wire and forming a fastening which tho not one hundred per cent efficient, would serve to guard against total disaster in case of failure in the solder. This idea is, as suggested by Professor Wells, to extend the wire thru the tube toward the end where the bolt hole is located and then give a number of turns around the outside of the tube as shown in the figure. Now should there be slipping of the wire in the solder which would generally be due to poor workmanship or should the solder pull out of the tube because of insufficient denting in of the tube, there would still be an opportunity for the wire to be effective to a certain extent.

An important disadvantage of this system is in the length of tube required,

and also the amount of solder used. As minimum weight is desired in the design of a connection, and length and cross sectional area are factors in determining the weight of the tube, it would be necessary to reduce the area by using steel in the tube which has a greater ultimate strength than Shelby tubing, as the length can not be varied for a particular size of wire.

CONNECTIONS

Connection Numbers	40	36	22	17
No. of Tests	30	20	20	20
Final no. of in. insert.	5½	4"	2½"	2"
Aprox. dia. of wire	1/8	1/10	1/16	1/20
Ultimate str. of connection.	3004	1955	638	410

Wire

No. of Tests	15	15	15	15
Ultimate str. of wire	2970	1952	575	385.

Fig. 1

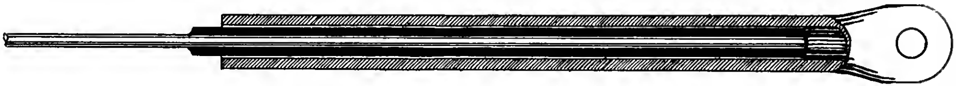


Fig. 2

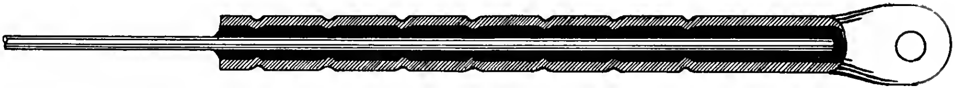


Fig. 3

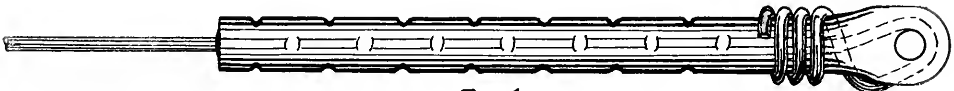
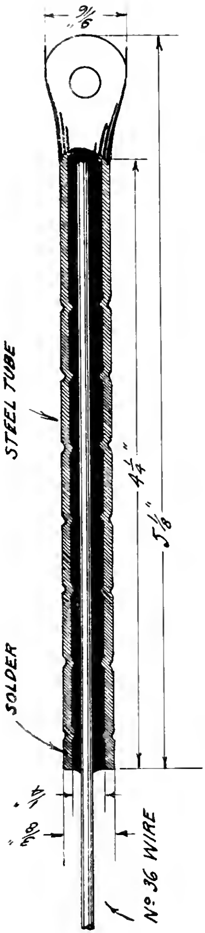


Fig. 4



9/16"
STEEL TUBE
4 1/4"
5 1/8"
SOLDER
1/4"
3/8"
No. 36 WIRE

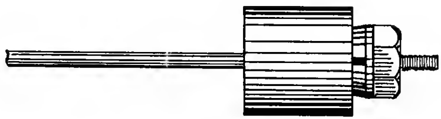


Fig 1

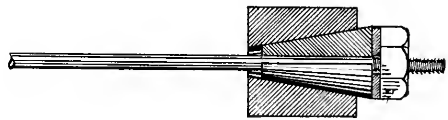


Fig. 2

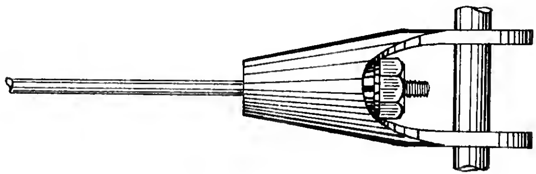
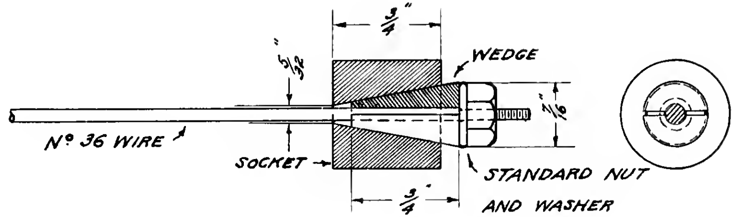


Fig. 3


Fig. 4


3/4"
5/32"
WEDGE
7/16"
Nº 36 WIRE
SOCKET
STANDARD NUT
AND WASHER
3/4"